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Original Article

Sleep problems in children with autism spectrum disorder: examining the contributions of sensory over-responsivity and anxiety

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ABSTRACT

Objectives: Children with autism spectrum disorder (ASD) are at high risk for sleep problems. Previous research suggests that sensory problems and anxiety may be related to the development and maintenance of sleep problems in children with ASD. However, the relationships among these co-occurring conditions have not been previously studied. The current study examined the interrelations of these symptoms in a large well-characterized sample of children and adolescents with ASD.

Methods: The current study examined the relationships among sleep problems, sensory over-responsivity, and anxiety in 1347 children enrolled in the Autism Speaks Autism Treatment Network. The primary measures included the Children's Sleep Habits Questionnaire, the Child Behavior Checklist, and the Short Sensory Profile.

Results: In bivariate correlations and multivariate path analyses, anxiety was associated with all types of sleep problems (ie, bedtime resistance, sleep-onset delay, sleep duration, sleep anxiety, and night wakings; $p < 0.01$ to $p < 0.001$; small to medium effect sizes). Sensory over-responsivity (SOR) was correlated with all sleep problems in bivariate analyses ($p < 0.01$ to $p < 0.001$; small effect sizes). In multivariate path models, SOR remained significantly associated with all sleep problems except night awakenings for older children, while SOR was no longer significantly associated with bedtime resistance or sleep anxiety for younger children.

Conclusions: Children with ASD who have anxiety and SOR may be particularly predisposed to sleep problems. These findings suggest that some children with ASD and sleep disturbance may have difficulties with hyperarousal. Future research using physiological measures of arousal and objective measures of sleep are needed.

1. Introduction

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder that is characterized by difficulties with social communication and interaction and by restricted and repetitive behaviors and activities [1]. In addition to these primary symptoms, individuals with ASD also experience high rates of medical and behavioral comorbidities [2,3]. Among these, sleep problems are particularly common for children with ASD, with prevalence rates ranging from 50% to 80% [4–7]. Most studies have found that difficulties falling asleep and night waking are the most common types of sleep problems in children with ASD, with additional evidence of disturbances in circadian rhythm [6,8]. For many children and families with ASD, sleep problems can contribute to significant distress and impairment over and above the effects of primary ASD symptoms. Sleep problems can have detrimental effects on learning and cognition [9], and they have been associated with an increased severity of stereotypic and challenging behaviors [10–12] and decreased quality of life [13] among children with ASD. Children's difficulties with sleep also affect the entire family, and they often result in increased parental stress and decreased well-being [14].

The etiology of sleep problems in children with ASD is thought to be multifactorial, including potential disruption in circadian rhythms and melatonin regulation and difficulties with sleep hygiene [6,15,16]. The majority of research and clinical practice guidelines for addressing sleep problems in children with ASD have focused on these factors. However, some researchers and clinicians have

Abbreviations: ASD, autism spectrum disorder; SOR, sensory over-responsivity; AS ATN, Autism Speaks Autism Treatment Network; ADOS, Autism Diagnostic Observation Schedule; MSEL, Mullen Scales of Early Learning; SSP, Short Sensory Profile; CBCL, Child Behavior Checklist; CSHQ, Children's Sleep Habits Questionnaire.

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suggested that hyperarousal [17–19] and sensory reactivity [8] may also play a role in the etiology of sleep problems in children with ASD. Although there is evidence to support this from the typically developing (TD) population [20–22], similar research has not yet been conducted among children with ASD.

In TD individuals, insomnia has been found to be associated with hyperarousal, cortical excitability, and hypothalamic–pituitary–adrenal (HPA)-axis involvement (as evidenced by increased cortisol secretion) [20,21]. It is possible that hyperarousal may also underlie sleep difficulties for children with ASD, particularly given their increased risk for arousal-related difficulties. In fact, compared to other clinical and nonclinical groups, children with ASD are at high risk for both anxiety [23,24] and sensory over-responsivity [25,26]. Importantly, these separate sets of symptoms are also characterized by hyperarousal. However, research has only recently begun to examine the possibility that these difficulties may relate to sleep problems in children with ASD [27,28].

1.1. Sleep problems and anxiety

There is strong evidence of comorbidity of anxiety and sleep problems in the general population, with a markedly high prevalence of insomnia among individuals with anxiety disorders (70–90%) [29]. In addition, studies of both adolescents and adults have found that anxiety is a longitudinal predictor of insomnia, predating the onset of insomnia in the great majority of cases, while depression appears to occur subsequent to insomnia [30,31]. These results provide evidence of a specific directional association from anxiety to insomnia in the general population.

There is a growing body of evidence that anxiety is also associated with sleep problems in individuals with ASD. For example, anxiety-related nighttime behaviors were common in a sample of 69 children with autism and sleep disturbance [32], parent-rated sleep disturbance was correlated with anxiety in children with autism [11], and sleep-related fears were found to be more common among children with Asperger's syndrome than among TD children [33]. Anxiety was also associated with insomnia in studies of adults with Asperger's disorder [34,35]. More recently, a study of children with intellectual disability and/or ASD found that sleep problems were significantly correlated with anxiety across the entire sample. However, separate results for the ASD group were not reported [36]. A recent analysis of the Autism Speaks Autism Treatment Network (AS ATN) registry database also found that children with ASD who had sleep problems had higher internalizing symptoms than those without sleep problems. However, although anxiety comprises an aspect of the larger internalizing symptom domain, the specific relationship between anxiety and sleep problems was not reported [37]. Richdale and Baglin found that sleep problems were associated with both parent- and self-reported symptoms of anxiety in a sample of 17 children with high-functioning ASD [18]. More recently, Richdale and colleagues found that adolescents with high-functioning ASD experienced more presleep arousal than TD adolescents, and that self-reported anxiety and presleep arousal were both correlated with sleep problems in the ASD group [28].

1.2. Sleep problems and sensory problems

Sensory over-responsivity represents another symptom area that has theoretical relevance to both anxiety and sleep problems. Sensory over-responsivity is common among children with ASD, with estimates ranging from 56% to 70% [38,39], and it is characterized by negative responses (eg, distress, avoidance, or hypervigilance) to specific sensory stimuli, such as light, sound, and/or tactile experiences [40,41]. There is increasing evidence that sensory over-responsivity and anxiety represent closely related yet conceptually distinct phenomenon [42]. Previous studies have found significant relationships between these variables in TD children [43,44], as well as children with ASD [45–47]. Similarly, there is some evidence that both conditions are characterized by increased HPA axis involvement [48]. This is not surprising given that the HPA axis regulates responses to stressful stimuli, and it is well connected to the amygdala, which is also activated by aversive stimuli from various sensory modalities [49].

Given that sensory over-responsivity, like anxiety, has been associated with hyperarousal, these particular symptoms may also be associated with sleep difficulties. In fact, there have been a few studies suggesting a link between sleep problems and sensory over-responsivity. Among TD children, sensory problems have been found to be associated with sleep problems [22]. Children with autism have also been found to have greater sensitivity to the sleep environment than children with other developmental problems [50]. More recently, a small study of 27 children with ASD found that sensory problems, particularly sensory avoiding, were correlated with sleep problems in children with ASD. Furthermore, physiological markers of stress, including salivary cortisol and galvanic skin response following the presentation of sensory stimuli, were highly related to sleep problems [27]. These preliminary findings indicate a need for further research on the relationships among sensory over-reactivity, anxiety, and sleep problems in children with ASD.

1.3. Current study

Evidence from previous studies provides a strong basis for predicting that sensory over-responsivity and anxiety may be highly related to the development and maintenance of sleep problems in children with ASD. The current study examined the possible interrelatedness of this group of symptoms among a large well-characterized sample of children and adolescents with ASD. The following hypotheses were tested:

1) Sensory over-responsivity will be associated with increased anxiety in children with ASD.
2) Anxiety will be associated with increased sleep problems in children with ASD.
3) Sensory over-responsivity will be associated with increased sleep problems in children with ASD.
4) Sensory over-responsivity and anxiety will each be associated with sleep problems in children with ASD when included jointly within a multivariate model.

2. Methods

2.1. Participants

Participants in the current study included 1347 children and adolescents enrolled in the AS ATN who had complete data on the measures required for the analyses. The AS ATN is a multisite network of autism treatment and research centers located throughout the United States and Canada. The AS ATN supports a large clinical registry database, which includes a standard battery of medical and behavioral measures collected at enrollment and across time. The current study examined cross-sectional data collected at enrollment into the AS ATN clinical registry. The AS ATN registry study was approved by the institutional review board at each site, informed written consent was obtained from all parents, and children provided assent when applicable and appropriate. All participants were assessed by AS ATN clinicians using a standard diagnostic battery, including clinical interview, the Autism Diagnostic Observation Schedule (ADOS) [51], cognitive assessment, and adaptive behavior assessment (using Vineland Adaptive Behavior Scales – Second Edition [52]). To be eligible for enrollment, participants were required to meet DSM-IV-TR diagnostic criteria

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[53] and have a confirmed diagnosis of an ASD (including autistic disorder, Asperger's disorder, and pervasive developmental disorder, not otherwise specified). Participants in the current study ranged from 2 to 17.6 years of age at enrollment, with a mean age of 7.9 years (standard deviation (SD) = 3.4). The majority of the sample was male (84.8%) and Caucasian (90.6%).

2.2. Measures

2.2.1. Sample characteristics

Child and family demographic data were collected at enrollment into the AS ATN clinical registry, including age, sex, race, and caregiver education level. Intelligence (intelligence quotient) was assessed at enrollment using a range of measures across sites, including the Stanford Binet Scales of Intelligence – Fifth Edition [54], the Wechsler Intelligence Scale for Children – Fourth Edition [55], the Wechsler Preschool and Primary Scale of Intelligence – Third Edition [56], the Wechsler Abbreviated Scale of Intelligence [57], the Differential Ability Scales, Second Edition [58], or the Mullen Scales of Early Learning (MSEL) [59]. For those receiving the MSEL, the Early Learning Composite Standard Score was used as a measure of Full Scale IQ.

2.2.2. Sensory over-responsivity

A subset of items from the Short Sensory Profile (SSP) [60] was used to assess sensory over-responsivity. The SSP is an abbreviated version of the Sensory Profile [61], and it consists of 38 parent-reported items assessing atypical sensory processing. The SSP has good psychometric properties and it is commonly used in studies of sensory processing in children with ASD [62–64]. Items on the SSP are rated on a five-point scale ranging from 1 (*Always*) to 5 (*Never*). Consistent with previous research on sensory over-responsivity in children with ASD [65,66], a sensory over-responsivity (SOR) score was derived by calculating the sum of all items on the following scales: Tactile Sensitivity (items 1–7), Taste/Smell Sensitivity (items 8–11), Movement Sensitivity (items 12–14), and Visual/Auditory Sensitivity (items 34–38). Note that lower item scores indicate greater difficulties on the SSP; thus, lower total SOR scores indicate greater over-responsivity.

2.2.3. Anxiety

Anxiety was assessed using the DSM-Oriented Anxiety Problems Raw Score from the Child Behavior Checklist (CBCL) [67]. The CBCL is a broadband parent-report questionnaire assessing symptoms across areas of emotional and behavioral functioning. Items are rated on a three-point scale (ranging from *Not True* to *Very True*). The CBCL has remarkable psychometric properties, which have also been supported in studies of children with ASD [68]. Separate versions of the CBCL are available based on age, the Preschool Version (for ages 1.5–5 years) and the School-Age Version (for ages 6–18 years). Both versions of the CBCL yield empirically derived Syndrome Scales and DSM-Oriented scales. The DSM-Oriented Anxiety Problems scale was chosen for the current study because it includes only items specific to anxiety (as opposed to the Anxious/Depressed Syndrome scale, which includes affective symptoms). Raw Scores were examined in the current analyses due to the fact that the CBCL DSM-Oriented T-scores are truncated (reducing variability at the lower end of the scales). Because the Anxiety Problems scale is comprised of different numbers of items across age-based versions, separate analyses were conducted based on the CBCL version administered.

2.2.4. Sleep problems

The *Children's Sleep Habits Questionnaire* (*CSHQ*) [69] was used to examine sleep problems. The CSHQ includes 45 parent-reported items assessing key sleep domains. The CSHQ has shown good internal consistency, reliability, and validity in previous research [69], and it has been widely used as a measure of sleep problems in children with ASD [7,70]. Although the CSHQ was originally developed and validated for use in children between the ages of 4 and 10 years [69], it has been previously used in studies of children as young as 2 years of age with and without ASD [71], and in studies of older children (up to age 18) with ASD [70,72].

The majority of CSHQ items are rated on a three-point scale (ranging from 1 = *rarely* to 3 = *usually*), comprise separate subscales, and can be summed to generate a Total Sleep Disturbance score [71]. For the current study, the sleep domains/subscales theoretically related to anxiety and sensory problems were examined in subsequent analyses: Bedtime Resistance, Sleep Onset Delay, Sleep Duration, Sleep Anxiety, and Night Wakings. The Sleep Disordered Breathing subscale was not included as a target variable given that these difficulties have identifiable etiologies [73] that are distinct from hyperarousal. Similarly, the Parasomnia subscale was excluded because of the wide range of difficulties included within this scale, ranging from sleepwalking to bruxism, which are also thought to have disparate etiologies [74,75]. Additionally, this subscale is likely not representative of a single construct, as evidenced by very low internal consistency, $\alpha = 0.36$ [69]. Finally, the Daytime Sleepiness subscale was excluded due to a significant amount of missing data (key items on the scale were rated as "not applicable" by a large number of individuals). Although daytime sleepiness may be an indicator of insomnia, the subscales chosen for inclusion were thought to be a more direct representation of sleep problems.

2.3. Data analyses

Descriptive statistics were conducted to characterize the sample and variables of interest. Pearson's correlation coefficients were used to examine the bivariate relationships between SOR, anxiety, and sleep problems (for Hypotheses 1–3). For Hypothesis 4, we were interested in estimating the strength of the relationship between five of the CSHQ subscales and SOR and anxiety, treating gender, IQ, and age as covariates. For ordinal and quantitative variables, scatter plots were first constructed to determine if there was evidence of any nonlinear associations. Rather than perform a separate regression analysis for each CSHQ outcome, path-modeling techniques were used to fit a single model with the CSHQ subscales as the dependent variables and SOR and Anxiety scores as the independent variables of primary interest. Age, IQ, and gender were included as covariates. Separate models were fit based on age and the CBCL version administered (ages 2–5, and ages 6–18). For each age group, the initial model was simplified by removing nonsignificant paths ($p > 0.05$) and refitting. Figure 1 illustrates the initial model.

3. Results

Table 1 provides sample characteristics of the younger (2–5 years) and older (6–18 years) groups.

3.1. Bivariate relationships: SOR and anxiety

To test the first hypothesis that SOR and anxiety would be strongly associated, Pearson's correlations were computed between the SOR score and CBCL Anxiety Problems Raw Scores for both the younger and older groups. Results indicated statistically significant correlations between anxiety and SOR for both the younger and older groups (see Table 2). Given that lower SOR scores indicate greater levels of difficulty with over-responsivity, this negative correlation supported our first hypothesis.

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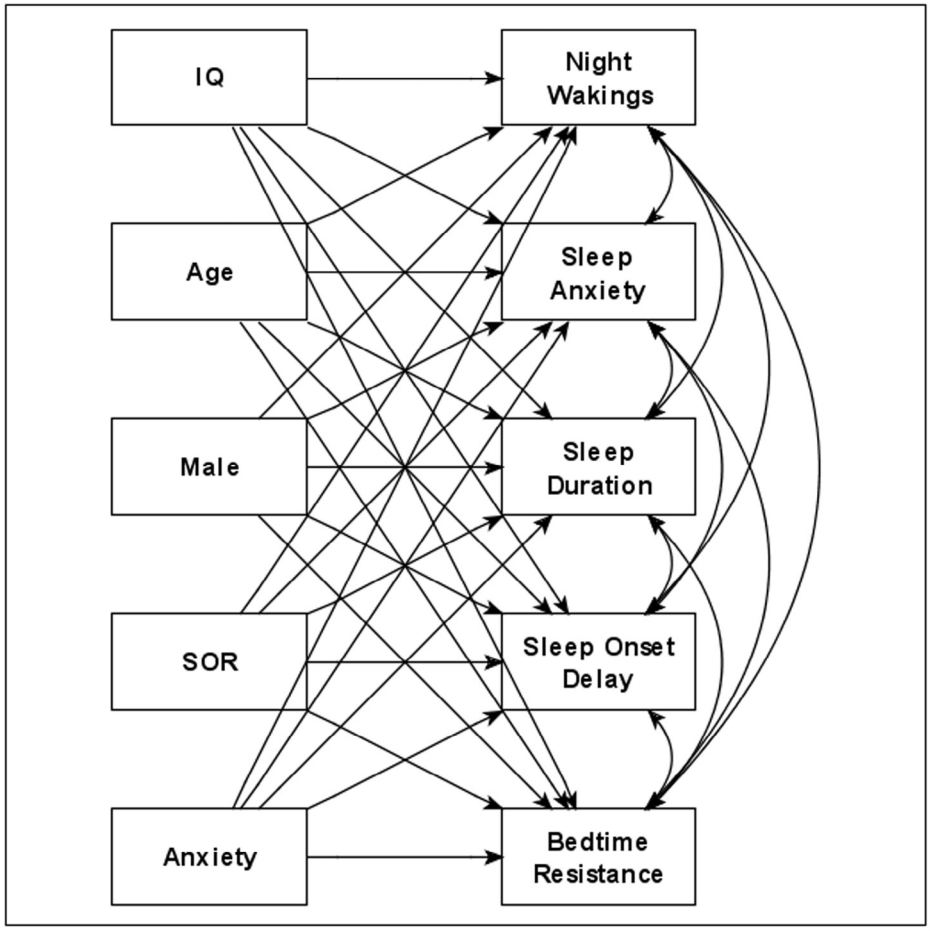

Fig. 1. Initial Path Model. Note: Single headed arrows depict regression relationships with the arrowhead pointing to the dependent variable. Two-headed arrows denote covariances between random error components. For simplicity, the specific error terms and the covariances between independent variables are not displayed in Fig. 1. The full model is a saturated model so no fit indices are displayed.

3.2. Bivariate relationships: anxiety and sleep problems

Pearson's correlations were also used to examine the relationship between anxiety and sleep problems (Hypothesis 2). Correlations between CBCL Anxiety Problems Raw Score and each selected CSHQ subscale score were computed for both the younger and older groups (see Table 2). The results indicated that for both age groups anxiety was significantly associated with each CSHQ subscale (including Bedtime Resistance, Sleep Onset Delay, Sleep Duration, Sleep Anxiety, and Night Wakings). For both age groups, the effect sizes ranged from small to medium.

3.3. Bivariate relationships: SOR and sleep problems

To test the third hypothesis that SOR would also be strongly associated with sleep problems, Pearson's correlations were computed between the SOR score and each selected CSHQ subscale score for both the younger and older groups (see Table 2). The results indicated that for both age groups SOR was also significantly associated with each CSHQ subscale (including Bedtime Resistance, Sleep-Onset Delay, Sleep Duration, Sleep Anxiety, and Night Wakings). The effect sizes were small across subscales for both age groups.

3.4. Multivariate model

As noted above, all variables were included in the initial path models for each age group, and the models were then simplified by removing nonsignificant paths ($p > 0.05$) and refitting. The results of the final, reduced models are described below.

The results for the final model for the younger age group are presented in Fig. 2 and Table 3, including both unstandardized and standardized parameter estimates. Standardized coefficients reflect the portion of an SD of change in the dependent variable for one SD change on the independent variable. The proportion of variance explained for each sleep outcome is also shown in Table 3. The results indicate that for the younger age group anxiety was significantly associated with each type of sleep problem, including bedtime resistance, sleep-onset delay, sleep duration, sleep anxiety, and night waking. Sensory over-responsivity was associated with sleep-onset delay, sleep duration, and night waking, but not with the remaining types of sleep problems.

Results for the final model for the older age group are presented in Fig. 3 and Table 4, including both unstandardized and standardized parameter estimates and the proportion of variance explained for each sleep outcome. For the older age group, anxiety was significantly associated with each type of sleep problem, including bedtime resistance, sleep-onset delay, sleep duration, sleep anxiety, and night waking. Sensory over-responsivity was associated with all sleep problems except night wakings.

4. Discussion

Medical problems frequently accompany the core symptoms of ASD and they can have a significant detrimental impact on health

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Table 1
Sample characteristics and descriptive statistics.

	Age 2–5 group ($n = 461$)		Age 6–18 group ($n = 886$)		Group comparisons[a]
Variable	*M* (SD)		*M* (SD)		*p*
Age	4.69 (0.79)		9.60 (2.91)		
Full Scale IQ	90.56 (19.39)		85.56 (22.39)		<0.001
Anxiety[b]	5.76 (4.09)		4.51 (2.92)		
SOR Score[c]	69.21 (14.53)		68.06 (14.19)		0.163
CSHQ[d] Bedtime Resistance	9.08 (3.36)		8.43 (2.88)		<0.001
CSHQ Sleep Onset Delay	1.60 (0.75)		1.77 (0.83)		<0.001
CSHQ Sleep Duration	4.02 (1.54)		4.42 (1.75)		<0.001
CSHQ Sleep Anxiety	6.32 (2.14)		6.03 (2.13)		0.02
CSHQ Night Wakings	4.57 (1.70)		4.21 (1.51)		<0.001
	n	%	*n*	%	
Gender					0.141
Male	382	82.9%	761	85.9%	
Female	79	17.1%	125	14.1%	
Race					0.709
Caucasian	403	90.2%	779	90.8%	
Non-Caucasian	44	9.8%	79	9.2%	
Caregiver education					0.114
Some high school	3	0.7%	9	1.1%	
High school	34	7.9%	80	9.4%	
Some college	122	28.3%	259	30.4%	
Bachelor's degree	133	30.9%	259	30.4%	
Postgraduate education	139	32.2%	246	28.8%	

[a] Group comparisons on continuous variables conducted by two-sample *t*-test, comparisons on caregiver education conducted with Wilcoxon rank sum test, and comparisons on gender and race conducted with chi-squared test.
[b] Child Behavior Checklist (CBCL) Anxiety Problems Raw Score.
[c] Sensory over-responsivity (SOR) calculated score from the Short Sensory Profile (SSP); lower scores indicate greater over-responsivity.
[d] Children's Sleep Habits Questionnaire (CSHQ).

and quality of life [76,77], yet the relationships among these problems are not well understood. Thus, the purpose of this study was to examine the relationships among three common co-occurring problems for children with ASD: sleep problems, sensory problems, and anxiety. Despite evidence suggesting that these three conditions may be highly related, this was the first study to examine their interrelations in children with ASD.

The results of bivariate analyses indicated that anxiety was significantly associated with all types of sleep problems of interest. Specifically, there was a positive correlation between anxiety and bedtime resistance, sleep-onset delay, sleep duration, sleep anxiety, and night wakings. Effect sizes ranged from small to medium in both the younger and older age groups. Similarly, sensory over-responsivity was significantly correlated with all sleep problems examined in both the younger and older age groups. These findings were consistent with our predictions, and they indicate that anxiety and sensory problems may be closely related to sleep disturbance children with ASD.

Table 2
Bivariate correlations among variables by age group.

	Age 2–5							
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Age								
(2) Full Scale IQ	0.11*							
(3) Anxiety	0.01	0.05						
(4) SOR Score	0.02	–0.03	–0.46***					
(5) CSHQ Bedtime Resistance	–0.08	–0.04	0.30***	–0.12**				
(6) CSHQ Sleep Onset Delay	–0.12*	–0.01	0.21***	–0.17***	0.36***			
(7) CSHQ Sleep Duration	–0.07	0.05	0.28***	–0.25***	0.35***	0.34***		
(8) CSHQ Sleep Anxiety	0.02	0.09	0.42***	–0.23***	0.78***	0.28***	0.34***	
(9) CSHQ Night Wakings	–0.05	–0.02	0.29***	–0.21***	0.41***	0.27***	0.45***	0.43***
	Age 6–18							
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Age								
(2) Full Scale IQ	–0.05							
(3) Anxiety[a]	0.03	–0.05						
(4) SOR Score[b]	0.08*	–0.05	–0.39***					
(5) CSHQ[c] Bedtime Resistance	–0.15***	–0.07*	0.24***	–0.18***				
(6) CSHQ Sleep Onset Delay	0.07*	0.04	0.15***	–0.16***	0.23***			
(7) CSHQ Sleep Duration	0.08*	0.01	0.23***	–0.19***	0.26***	0.48***		
(8) CSHQ Sleep Anxiety	–0.16***	0.01	0.36***	–0.29***	0.73***	0.19***	0.23***	
(9) CSHQ Night Wakings	–0.09**	–0.07*	0.14***	–0.09**	0.41***	0.18***	0.30***	0.38***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
[a] Child Behavior Checklist (CBCL) Anxiety Problems raw score.
[b] Sensory Over-Responsivity (SOR) calculated score from the Short Sensory Profile (SSP), lower scores indicate greater over-responsivity.
[c] Children's Sleep Habits Questionnaire (CSHQ).

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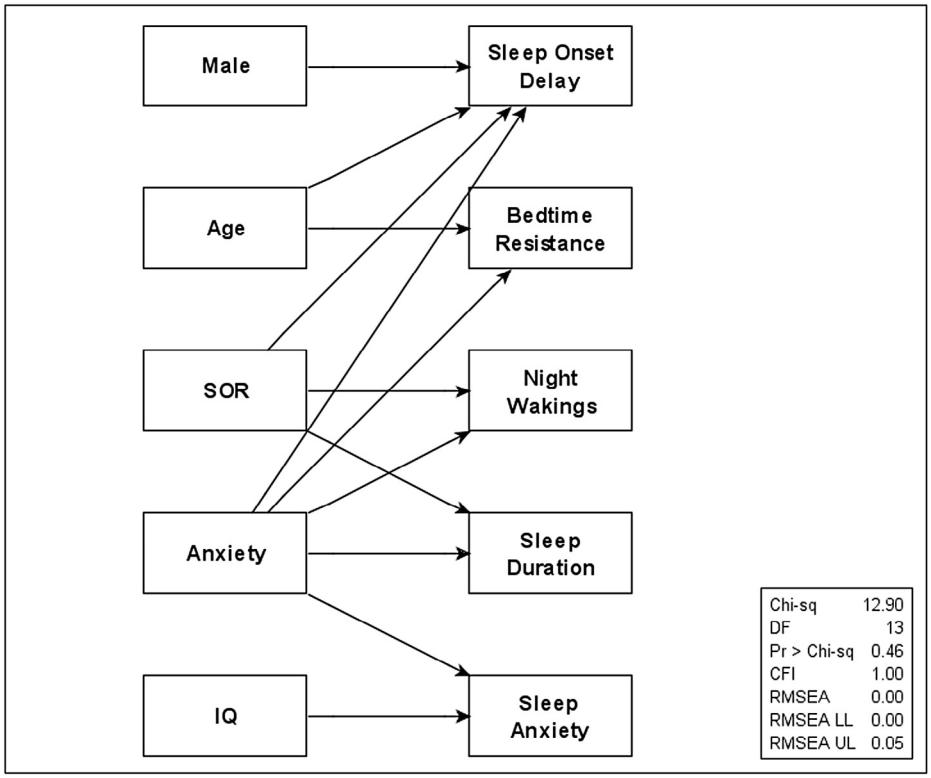

Fig. 2. Final Model for Ages 2–5. Note: Displayed paths are the statistically significant ($p < 0.05$) regression relationships. Covariance terms are suppressed for simplicity.

In order to examine the strength of associations between individual sleep problems, anxiety, and sensory over-responsivity, we utilized path-modeling techniques to fit a single model for each age group while controlling for covariates. The results of the path model for the younger age group (ages 2–5 years) indicated that, even after accounting all other variables, anxiety was significantly associated with all types of sleep problems. By contrast, sensory over-responsivity was associated with sleep-onset delay, sleep duration, and night awakenings, but not with the remaining types of sleep problems. For the older age group (ages 6–18 years), both anxiety and sensory over-responsivity were associated with all types of sleep problem with the exception of night awakenings, which was not associated with sensory over-responsivity.

These data provide support for the idea that sleep problems in many children with ASD may be due to arousal dysregulation. In fact, anxiety in children is known to be associated with physiological hyperarousal [78,79], and the strong association between anxiety and sleep disturbance in the current sample suggests that hyperarousal may represent a shared underlying mechanism of both anxiety and sleep disturbance in children with ASD. Sensory over-responsivity, also potentially related to arousal dysfunction, was also associated with sleep problems in all bivariate analyses. However, when sensory over-responsivity was included within the same model as anxiety and other covariates, the associations with bedtime resistance and sleep anxiety were no longer statistically significant for the younger age group. For the older group, sensory over-responsivity remained significantly associated with all but one type of sleep problem (night awakenings).

Children with ASD who have anxiety and sensory over-responsivity may be particularly predisposed to sleep problems. Due to difficulties regulating arousal, children with ASD and anxiety may have trouble falling asleep due to increased physiological arousal and autonomic activity. A number of studies have demonstrated this finding among adults with insomnia, with evidence of increased arousal across a number of physiological measures. These have included increased heart rate [80,81], increased levels of cortisol

Table 3
Final path model results for ages 2–5.

Outcome variable	Independent variable	Unstandardized path coefficient (SE)	p	95% CI	Standardized path coefficient	R^2
Bedtime Resistance	Anxiety	0.25 (0.04)	<0.001	(0.18, 0.32)	0.30	0.10
	Age	–0.32 (0.12)	0.008	(–0.56, –0.08)	–0.08	
Sleep-Onset Delay	Anxiety	0.03 (0.01)	0.004	(0.01, 0.05)	0.15	0.07
	SOR	–0.01 (0.00)	0.018	(–0.01, 0.00)	–0.11	
	Age	–0.09 (.04)	0.03	(–0.17, –0.01)	–0.09	
	Male	–0.21 (0.08)	0.010	(–0.38, –0.05)	–0.11	
Sleep Duration	Anxiety	0.08 (0.02)	<0.001	(0.04, 0.12)	0.21	0.10
	SOR	–0.02 (0.01)	0.002	(–0.03, –0.01)	–0.15	
Sleep Anxiety	Anxiety	0.22 (0.02)	<0.001	(0.17, 0.26)	0.41	0.18
	IQ	0.01 (0.00)	<0.001	(0.01, 0.02)	0.10	
Night Wakings	Anxiety	0.10 (0.02)	<0.001	(0.06, 0.14)	0.25	0.09
	SOR	–0.01 (0.01)	0.055	(–0.02, 0.00)	–0.09	

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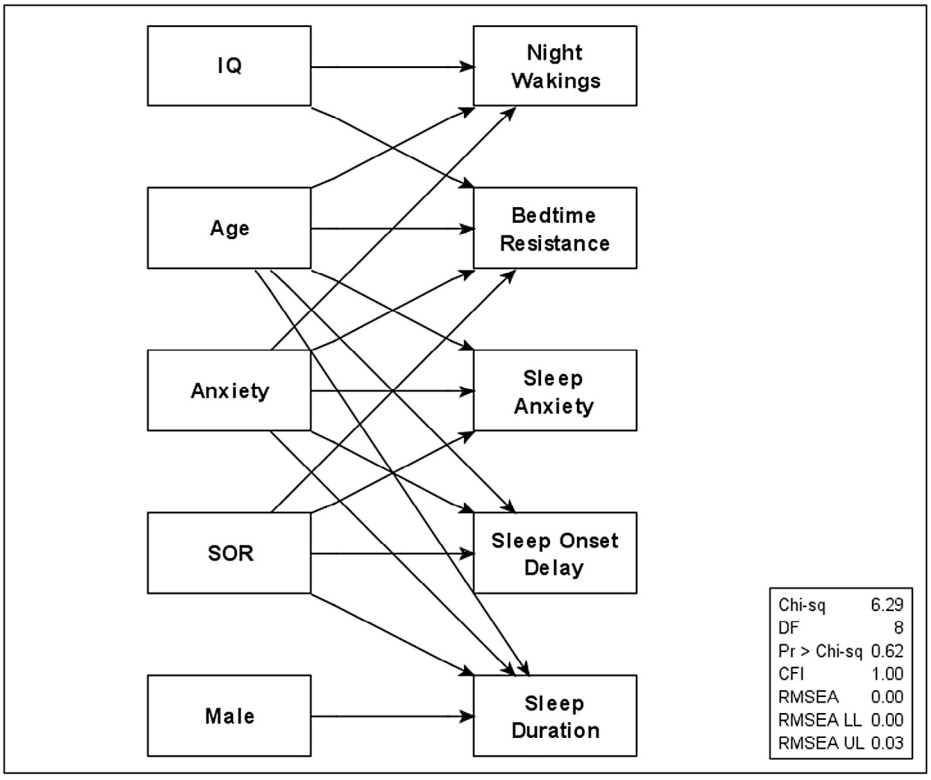

Fig. 3. Final model for ages 6–18. Note: Displayed paths are the statistically significant ($p < 0.05$) regression relationships. Covariance terms are suppressed for simplicity.

[82–84], and increased cortical arousal during sleep [85] in adults with insomnia compared to adults with good sleep. Additional research is needed among children with ASD to determine if similar physiological markers of arousal are present among those with sleep disturbance.

In addition to physiological hyperarousal, it is possible that cognitive processes may also play a role in insomnia for some children and adolescents with ASD, as hypothesized by Richdale and colleagues [28]. The cognitive model posits that intrusive thoughts and worries about sleep during the presleep period trigger increased physiological arousal and emotional distress, leading to continued cognitive activity, and subsequently interfering with sleep onset [86]. Consistent with this idea, Richdale and colleagues [28] examined self-reported presleep cognitive and somatic arousal among a sample of 26 adolescents with ASD and 27 TD adolescents. The results indicated that the ASD group reported higher levels of cognitive arousal than the TD group, and that presleep cognitive arousal was associated with a number of measures of insomnia. Future research among high-functioning children and adolescents with ASD is needed to continue to examine whether cognitive processes contribute to the development or maintenance of insomnia in this group.

Difficulties with sensory processing may also interfere with sleep for children who are over-responsive to sensory input. In this case, children may be especially sensitive to the effects of stimuli within the sleep environment. These stimuli, which may include noise, light, temperature, or tactile input, may directly interfere with falling asleep or staying asleep. The current results suggest that this may be true for younger children with ASD, for whom sensory over-responsivity

Table 4
Final path model results for ages 6–18.

Outcome variable	Independent variable	Unstandardized path coefficient (SE)	p	95% CI	Standardized path coefficient	R^2
Bedtime Resistance	Anxiety	0.21 (0.03)	<0.001	(0.15, 0.28)	0.22	0.09
	SOR	–0.02 (0.01)	0.019	(–0.03, 0.00)	–0.08	
	IQ	–0.01 (0.00)	<0.001	(–0.02, 0.00)	–0.08	
	Age	–0.16 (0.03)	<0.001	(–0.22, –0.09)	–0.16	
Sleep Onset Delay	Anxiety	0.03 (0.01)	0.006	(0.01, 0.05)	0.10	0.04
	SOR	–0.01 (0.00)	<0.001	(–0.01, 0.00)	–0.13	
	Age	0.02 (0.01)	0.024	(0.00, 0.04)	0.08	
Sleep Duration	Anxiety	0.11 (0.02)	<0.001	(0.06, 0.15)	0.18	0.08
	SOR	–0.02 (0.00)	<0.001	(–0.02, –0.01)	–0.13	
	Age	0.05 (0.02)	0.008	(0.01, 0.09)	0.09	
	Male	–0.38 (0.14)	0.007	(–0.65, –0.10)	–0.08	
Sleep Anxiety	Anxiety	0.23 (0.02)	<0.001	(0.18, 0.27)	0.31	0.18
	SOR	–0.02 (0.01)	<0.001	(–0.03, –0.01)	–0.14	
	Age	–0.12 (0.02)	<0.001	(–0.16, –0.07)	–0.16	
Night Wakings	Anxiety	0.08 (0.02)	<0.001	(0.04, 0.11)	0.15	0.04
	IQ	–0.01 (0.00)	0.012	(–0.01, 0.00)	–0.08	
	Age	–0.05 (0.02)	0.002	(–0.09, –0.02)	–0.10	

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was significantly associated with sleep-onset delay, sleep duration, and night awakenings within the multivariate path model. Similar findings have been reported among adults with insomnia. For example, Milner and colleagues found that adults with primary insomnia showed sensory gating impairments in the period before sleep compared to normal sleepers (as evidenced by lower P50 amplitudes in response to stimuli) [86]. The authors concluded that these data provided evidence of increased sensory processing and hyperarousal prior to sleep, leading to disruptions in sleep onset [87]. Similar studies are needed on children with ASD to determine whether physiological measures of sensory processing difficulties also correlate with sleep disturbance in this population. Bedtime resistance and sleep anxiety were not associated with sensory over-responsivity for the younger group. It appears that anxiety may play a larger role than sensory problems in contributing to sleep anxiety and bedtime resistance for young children. In contrast, sensory over-responsivity was not associated with night awakenings for older children in the multivariate model. However, it should be noted that parents may not be accurate reporters of night awakenings for older children, particularly for children who are more self-sufficient and may not awaken their parents [70].

4.1. Strengths and limitations

This study was the first to examine the relationships among sleep problems, anxiety, and sensory over-responsivity in children with ASD. The AS ATN registry provided a large geographically diverse sample of children with well-characterized ASD, and it also allowed the examination of these variables across a wide age range. However, the study relied on parent report for the variables of primary interest, including sleep, anxiety, and sensory problems. Although these parent-report measures have been widely used among children with ASD and have demonstrated good psychometric properties, future studies would benefit from a more comprehensive approach. In particular, multi-method assessments of all constructs would be ideal. This should include physiological measures of anxiety, arousal, and sensory processing as well as objective measures of sleep such as actigraphy or video polysomnography. Objective measures of sleep would be especially helpful for older children and adolescents, as parents may be less reliable reporters of sleep quality and night awakenings in this group [88]. Although self-report of symptoms may also be helpful in TD populations, there are often barriers to self-report in children with ASD, including communication difficulties and problems describing emotional experiences [89,90].

4.2. Conclusions and clinical implications

The results of the current study provide preliminary information about potential mechanisms underlying these common problems in children with ASD. We hope that this knowledge will inform the development of targeted treatments, as well as enhancing our understanding of potential phenotypic subtypes within the ASD population. These findings suggest that children with ASD and sleep disturbance may have difficulties with hyperarousal; however, additional research using physiological measures of arousal and objective measures of sleep are needed. Longitudinal studies would also be helpful to identify patterns of sleep, anxiety, and sensory processing over time. Ultimately, this research is essential in order to develop the most effective treatment paradigms for sleep disturbance among children with ASD. If hyperarousal is a common underlying mechanism for insomnia in children with ASD, treatments that reduce physiological arousal may be beneficial in both reducing anxiety and improving sleep.

Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2014.11.006.

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